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ABSTRACT

Two types of questions may be asked in educational inquiry: educological ones--those seeking descriptions of educational events, and programmatic ones--those seeking prescriptions for educational interventions. Quantitative educology is described as consisting of three branches: the philosophy, science, and praxiology of education. The SIGGS Theory Model--which integrates set, information, graph, and general systems theories--is presented and discussed with respect to educational research. Psychological and sociological approaches to scientific educational research reduce a system to its individual research parts. In contrast, the systems approach and the cybernetic model are non-reductionistic and take homeostasis to be the proper system's state. The SIGGS Theory Model extends the cybernetic model through transactional functions, and thus allows for characterization of educational systems that include the deliberate attempts of both teachers and students to influence educational events. A chart is used to compare four models of educational theory--psychological, sociological, cybernetic, and SIGGS--with respect to their complexity, organization, aggregativeness, separability, continuity, sequentiality, interdependence, and self-regulation. Finally, the uses of the model are described, as it might have been applied to the work of Coleman on desegregation and associated population shifts, the work of Mumford on so-called "white flight", and the work of Sennel and Frick on a computer-assisted teacher education approach. (Author/GDC)

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**USES OF SIGNS
IN
EDUCATIONAL RESEARCH**

by

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**American Educational Research Association
New York
April, 1977**

In the first portion of this paper a brief explication of educational inquiry will be presented. In the second part of the paper a brief explication of the SIGGS Theory Model will be set forth. In the remaining portions of the paper, uses of SIGGS in educational research will be discussed.

I Educational Inquiry

Two kinds of questions about education can be asked: educological (1) ones, those seeking descriptions of educational events, and programmatic ones, those seeking prescriptions for educational interventions. The educologist (educational researcher) offers descriptions. The educational developer offers prescriptions. Obviously, both research and development are requirements for adequate educational practice.

In research the quest is toward the production of knowledge. Although knowledge can be either quantitative or qualitative or performative, our discussion of educational research will be limited to that which produces quantitative educology. Quantitative educology consists of descriptions of educational states of affairs as instances of classes. Class logic or quantification is its basic form.

Quantitative educology consists of three branches: philosophy of education, science of education, and praxiology of education. If the knowledge is descriptive of ideal states of affairs, it is

philosophical. It is normative insofar as descriptions of the ideal provide standards for judging whether states of affairs are true or good or properly ordered. If the knowledge is descriptive of states which have, are, or will be, it is scientific. Finally, if the knowledge is descriptive of effective states of affairs, it is praxiological. It is normative insofar as descriptions of effectiveness provide standards for judging the merit of means relative to ends.

II

The SIGGS Theory Model

Since the logic of the SIGGS Theory Model was presented at last year's meeting in San Francisco (2), only a brief description of the model will be given here. When illustrating uses of SIGGS in educational research, appropriate details will be explicated.

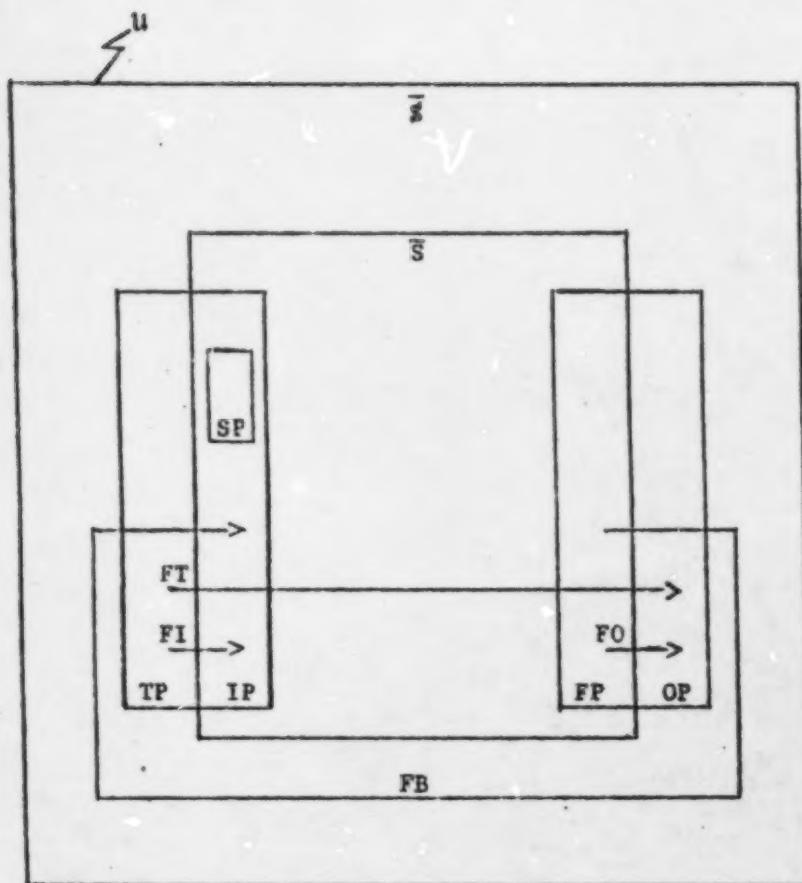
The model consists of a group of related terms. The terms are related so that some are primitive or undefined and others are defined. All defined terms are defined through primitive terms or through defined terms previously defined by means of primitive terms. Since the terms are characterizations with respect to a system in general and not with respect to one kind of system, e.g. an educational one, the theory model can be said to be a group of related characterizations about a general system or a general system descriptive theory.

The acronym, 'SIGGS', denotes an integration of set, information,

graph, and general systems theories. Through set theory, marking off of systems is through the set characterization, complement. Within whatever universe of discourse is selected, the complement marks off the system from its surroundings, the negasystem. The components which do not belong to the system is its negasystem.

Through information theory, an extension of system properties was accomplished. Using the condition of selectivity, meaning was given to toputness, inputness, fromputness, and outputness. Conditional selective information gives meaning to storeputness, for storeputness is system selective information which results when one takes into account the dependency of system selective information upon that available to a negasystem. Feedinness, feedoutness, feedthroughness, and feedbackness are properties in which there is a flow of selective information. Hence, conditions of selective information separated by time intervals and sharing of selective information are requirements. To illustrate; feedinness is shared information between toputness and inputness, where toputness is at a time just prior to the inputness. Schema 1 represents the information theoretic properties of SIGGS.

Using digraph theory, a system group (subsystem) becomes a set of points and system affect relations become sets of directed lines. Digraph properties of a system result when certain conditions are placed on its affect relations or its group. Such properties are of connectedness of groups within the system.



'u' stands for universe of discourse
 's' stands for educational system
 's̄' stands for surroundings
 'SP' stands for storeputness
 'FT' stands for feedthroughness
 'FI' stands for feedinness

'TP' stands for toputness
 'IP' stands for inputness
 'FO' stands for feedoutness
 'FP' stands for fromputness
 'OP' stands for outputness
 'FB' stands for feedbackness

SCHEMA 1: INFORMATION THEORETIC PROPERTIES OF SIGGS

Through general systems theory, an organismic focus is provided. Extended as above through set theory, information theory, and graph theory, this organismic focus is developed to treat of the complexities of configurations.

III SIGGS and Scientific Educational Research

In scientific educational research, the dominating theory models are mechanistic. A psychological or a sociological educative effects theory model is employed. The psychological educative effects model differs from the sociological one with respect to the treatment of complexity and organization. Since the psychologist takes an experimentalist's stance, a reductive view of the educative event is required. In the psychological view, teacher-learner systems are reduced to ones containing a small number of factors. Background factors, e.g., social status of the learner or of the teacher, and learner intention, are controlled through manipulation of the educative process so that they are not permitted to have an effect on student achievement. Schema 2 represents the psychological educative effects model. In this model, measures of student achievement are taken as linear and additive.

Since the sociologist takes a naturalistic stance, reduction of the number of factors to enable calculation is not necessary. The sociologist accounts for rather than controls factors. Accounting is through statistical analysis of observed background



SCHEMA 2: PSYCHOLOGICAL EDUCATIVE EFFECTS MODEL

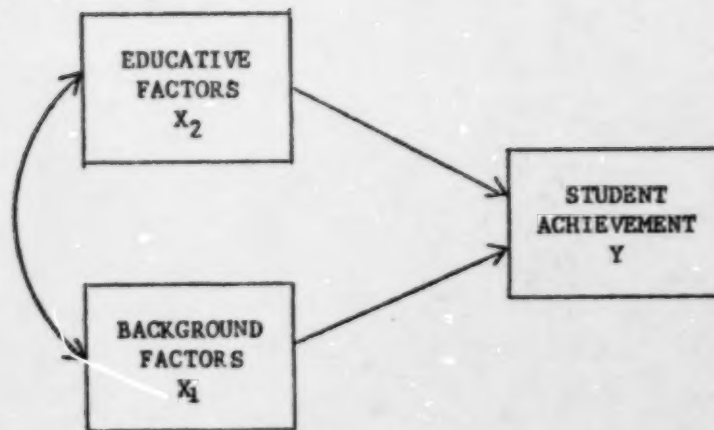
factors and of observed educative ones. In common practice, regression analysis is used for sorting factors and for determining the significance of the sorts. Linear and additive requirements in measurement are retained. These requirements are necessary for the solution of such equations as

$$B_1X_1 + B_2X_2 = Y + e$$

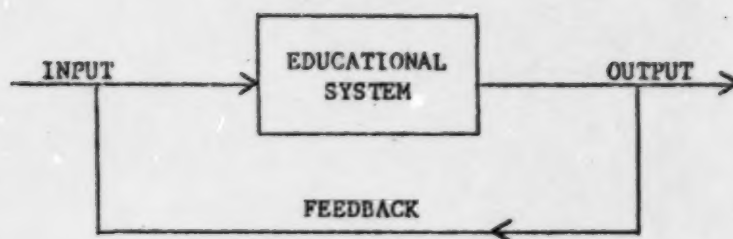
where X_1 , X_2 and Y are interpreted as in Schema 3; and B is the number of units Y is expected to increase for an increase in one unit of X , and e is an error term. The use of such equations restricts measures. And so evaluation in the framework of the sociological educative effects model is just as reductive as in the psychological educative effects model.

Recently educational researchers have been investigating the dynamics of human cultivation. In so doing they have been using educative configuration models. Often a version of the cybernetic systems model serves as a perspective for research. Understanding of regulation of the dynamics of teacher-learner systems is sought through construction of feedback loops. Positive feedback loops that lead to destructing dynamics are not investigated. In order to obtain homeostasis in educational systems, negative feedback loops are incorporated. A configurational model which is a cybernetic educational theory model is represented in Schema 4.

Ervin Laszlo argued that general systems theory is a non-reductionistic simplification of nature and the universe.



SCHEMA 3: SOCIOLOGICAL EDUCATIVE EFFECTS MODEL



SCHEMA 4: CYBERNETIC EDUCATIONAL THEORY MODEL

Many different kinds and orders of things are not treated as different aggregates of the same units. Wholes are not reducible to parts. However, the wholes are variations of common organizational patterns. In Laszlo's words, systems theory

. . . discovers repeating patterns in organization such as floors, doors and windows, and evaluates these as so many variations on a common theme. But it does not hold that you can reduce a barn, a home and an office building to sameness by taking them apart to individual pieces of brick and concrete. Such reduction eliminates precisely that which is essential about each structure: the organization of the materials into variously functioning modules. (3)

In this system theoretic perspective, learners are a complex of interactions internal and with teachers, curricula, and settings. These interactions function not only for system maintenance but also for system enhancement.

Usual characterizations of systems theory take homeostasis to be the proper system's state. Equivalence relations between systems and environment are sought. Often the familiar cybernetic model is employed. Von Bertalanffy noted that such characterizations of systems are too restrictive. (4) They are mechanistic not organismic characterizations.

The SIGGS theory model extends the cybernetic model through transaction. Transactional functions permit intention and thus allow for characterization of educational systems that include both the deliberate attempts of teachers and learners. Both the

teacher and student are agents of influence. With such influence affect, mutuality can result only if teacher and student attempts are directed toward the same end. SIGGS is a model that makes possible analysis of teacher-student transactions. Schema 1 presents SIGGS, an educative configuration model which is transactional.

Table 1 presents a comparison of the kinds of educational theory models that can be used in scientific educational research. Their essential characteristics are listed.

To illustrate the use of SIGGS in scientific educational research, the research by Coleman et. al. (5) on the relation between desegregation and the exodus of white population from larger central-city schools as well as the research of some of his critics will be discussed. The discussion will be in terms of the research variables and their relations with respect to SIGGS.

The question that Coleman sought to answer was: What effect has school desegregation on the loss of white school children from large central-city school districts? He assumed that by examining change in school enrollments during the period between 1968 and 1973 he could answer this question. He developed a standard segregation index by correlating the average proportion of white children in the average black child's school district with the proportion of whites in metropolitan areas. Change in white student enrollment was indicated by the ratio between enrollment change of white students in a given year and the enrollment of white students

	MODELS			
	Educative Effects		Educative Configurations	
	Psychological	Sociological	Cybernetic	SIGGS
Complexity	Simplicity	Complexity	Complexity	Complexity
Organization	Organized	Unorganized	Organized	Organized
Aggregativeness	Whole is sum of parts	Whole is sum of parts	Whole is more than sum of parts	Whole is more than sum of parts
Separability	Whole can be broken down into component parts	Whole can be broken down into component parts	Wholes are irreducible	Wholes are irreducible
Continuity	Linearity	Linearity	Discontinuity	Discontinuity
Sequentiality	Sequentiality	Sequentiality	Non-sequentiality	Non-sequentiality
Interdependence	Parts can be treated in isolation	Parts can be treated in isolation	Feedback	Feedback & feedthrough
Self-regulation	Non-self-regulation	Non-self-regulation	Self-regulation	Self-regulation

TABLE 1: COMPARISON OF EDUCATIONAL THEORY MODELS

in the previous year.

The equation used in the calculation of change in enrollment of white students shows that Coleman used the sociological educative effects model. That equation is

$$\frac{w_t - w_{t-1}}{w_{t-1}} = a + b_1 \Delta r_{t,t-1} + b_2 P_{b,t-1} + b_3 I_n N_{t-1}$$

where

w_t is number of white students in the system in year t

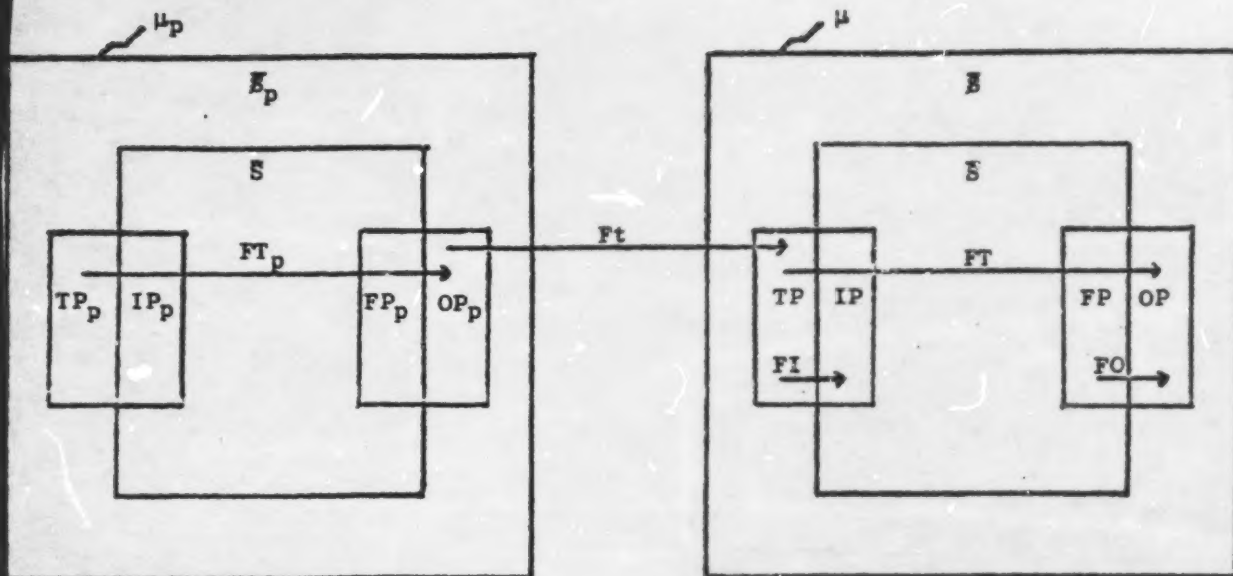
r_t is the standard measure of segregation in year t

$P_{b,t-1}$ is the proportion of black students in the system in year $t-1$, and

N_{t-1} is the number of students in the system in year $t-1$

Variables used in calculating standard measure of segregation r_t would parallel in SIGGS, feed to the educational system from the population system and feed in to the educational system. See Schema 5. Change in white student enrollment is a comparison between two categories of educational system input over one year.

Robert L. Green and Thomas F. Pettigrew (6) critiqued Coleman's study. They pointed out that the predictive power in Coleman's equation is a function of change in black student enrollment in the city's school districts relative to that of white students. They also discussed the significance of R. Farley's study based on the same data source as Coleman's. Farley sampled



'p' stands for population, 'Ft' stands for feedtoness, other symbols are interpreted in Schema 1.

SCHEMA 5: RELATION OF POPULATION AND EDUCATION SYSTEMS

districts that differed in size from those chosen by Coleman and related variables over a five-year period. He compared change of student enrollment in desegregated schools with those of non-desegregated schools and found that enrollment loss of white students in desegregated schools was not greater than such loss in non-segregated schools.

The longitudinal analysis employed by Farley is more in keeping with an attempt to delineate trends than is the episodic analysis used by Coleman. The SIGGS conceptual framework would be of help here since trends are flows and so ways in which a system functions through time. Moreover, SIGGS would overcome the difficulties related to measures that are summed to presumably yield trends. Questions of change in the status of system maintenance, as those in Coleman's white flight, can be answered through measures suited to homeostatic functions. These measures are of duration of effects, and thereby are longitudinal.

In another study cited by Green and Pettigrew, the investigator, Luther Mumford, concluded that "white flight" was explained by the black/white ratio in the population as a whole rather than solely by the proportionate enrollment of black and white students in schools. This observation by Mumford certainly is a perspective called for by SIGGS. Mumford's findings indicate that researchers should consider toputness (in this case black/white students available for enrollment into schools) as well as enrollments of black and

white students. Mumford more clearly structured his investigation to satisfy the requirements of flow measures, in this case feedinness (commonality between black and white students available for enrollment and actual enrollment of such students).

Neither Coleman's study nor Mumford's with its improved investigative vision was adequate for the understanding of population shifts. To locate determinants of population changes, look to the population not to the schools. School effects do not necessarily mirror population effects. As Schema 5 displays, output of a population system is not necessarily input of a school system.

The use of SIGGS for a study like Coleman's would have led to the avoidance of undue simplification which Rossell (7) attempted to overcome. Christine Rossell did two things that would have been called for in SIGGS. She extended the time period of analysis by starting before 1967, and increased the topup and input to include degrees (low, medium, and high) of court ordered and non-ordered segregation. Extended arrays of categories are necessary if a researcher is to avoid undue simplification of the complex system exchanges. Through Green and Pettigrew's own study (8), they found that black student enrollment was increasing through time. Consequently, sufficient evidence for Coleman's conclusion of white flight was lacking. Obviously all relevant components of a system must be examined. Coleman should have examined black as well as white populations. Distortion occurred through sub-set selection.

SIGGS would have prevented the over-simplification of either the calculations or the data source. Given the requirement that occurrences transmitted from toputness categories must be isomorphically mapable into inputness categories, variables selected from the population system would not differ from those selected from the educational system.

In Table 2, the extension of the variables in Coleman's study is summarized. It should be noted that only in SIGGS are the variables specified through information theoretic measures. SIGGS's perspective extends beyond what the table reveals.

Given the wider perspective available through SIGGS, how would a researcher proceed? As suggested in Schema 5, "white flight" is a change in a population system which can be indicated by change in an educational system. In order to understand the determinants of school enrollment change (one change might be "white flight"), changes within and interchanges between both the population and education systems must be examined.

Also since "white flight" is a consequence of population change, comparisons of cities included through indices as size is much too risky. This is borne out by the effect on Coleman's predictions from inclusion of Memphis and Atlanta. When Green and Pettigrew removed the effects due to these two cities, the average estimated loss of whites at 5.2% dropped to 1.5%. Since SIGGS requires an analysis of systems taken as wholes, this kind of error is eliminated.

PERSPECTIVE	VARIABLES	
Coleman	P_W	S_W, S_B
Mumford	P_W/P_B	S_W, S_B
Rossell	P_W/P_H	S_W, S_B
	O $\bar{O}$	
	H, M, L H, M, L	
Green & Pottigrew	P_W/P_B	S_W, S_B
SIGGS	TOPIUT	INPUT

TABLE 2: EXTENSION OF VARIABLES IN COLEMAN'S STUDY

'P_W' stands for white population
 'P_B' stands for black population
 'S_W' stands for white students
 'S_B' stands for black students
 'O' stands for court-ordered segregation
 'H, M, L' stands for high, medium, low

Calculations, of course, would be more cumbersome and a single data source with required specifications might not be available. Thus, analysis through SIGGS could not be as sweeping as Coleman's analysis, but the risk of error would be diminished thereby.

The following proposition characterizes the determinants of "white flight" and other school enrollment:

$$\begin{aligned} \overline{FT}_{P_W} \downarrow \wedge \overline{FT}_{P_B} \uparrow \vee \overline{FT}_{P_B} \rightarrow &:= \overline{Ft}_{P_W,E} \downarrow \wedge \overline{Ft}_{P_B,E} \uparrow \\ \vee \overline{Ft}_{P_B,E} \rightarrow &:= \overline{FT}_{E_W} \downarrow \wedge \overline{FT}_{E_B} \uparrow \vee \overline{FT}_{E_B} \rightarrow \wedge \overline{FP}_{E_W} \uparrow \\ \wedge \overline{OP}_{E_W} \downarrow \wedge \overline{FP}_{E_B} \uparrow \vee \overline{FP}_{E_B} \rightarrow &\wedge \overline{FO}_{E_B} \uparrow \vee \overline{FO}_{E_B} \rightarrow \end{aligned}$$

The reading of the proposition is as follows:

If, the population feedthrough of whites below a certain value decreases and that of blacks above a certain value increases or remains constant, only if the population feedto of whites to education below a certain value decreases and that of blacks above a certain value increases or remains constant, then the education feedthrough of whites below a certain value decreases and that of blacks above a certain value increases or remains constant and the education fromput of whites above a certain value increases and the output below a certain value decreases and the fromput of blacks above a certain value increases or remains constant and the feed-out of blacks above a certain value increases or remains constant.

The proposition only requires redundant application of Shannon's

H and T measures. Using Shannon's information measure (H)

$$H(C) = -\sum_{i=1}^n p(c_i) \log_2 p(c_i)$$

where $p(c_i)$ is the probability of category c_i at classification c

toputness, inputness, fromputness, and outputness can be calculated.

With H and Shannon's shared information measure (T)

$$T(C_I, C_J) = H(C_I) + H(C_J) - H(C_{IJ})$$

feedthroughness can be calculated.

$$\begin{aligned} FT &= T(TP, IP, FP, OP) \\ &= H(TP) + H(IP) + H(FP) + H(OP) \\ &\quad - H(TP, IP) - H(TP, FP) - H(TP, OP) \\ &\quad - H(IP, FP) - H(IP, OP) - H(FP, OP) \\ &\quad + H(TP, IP, FP) + H(TP, IP, OP) + \\ &\quad H(TP, FP, OP) + H(IP, FP, OP) - H(IP, FP, OP) \\ &\quad - H(TP, IP, FP, OP) \end{aligned}$$

Feedtoness also can be calculated.

$$\begin{aligned} Ft &= T(OP, TP) \\ &= H(OP) + H(TP) - H(OP, TP) \end{aligned}$$

III

SIGGS and Praxiological Educational Research

Semmel and Frick are conducting praxiological educational research in which SIGGS is being used. (9) They are investigating the effectiveness of a general systems approach in teacher education and in so doing are utilizing CARTLO.

CARTLO is an acronym for computer-assisted retroduction of teaching-learning outcomes. This teacher education approach is an integration of CATTs, computer-assisted teacher training system and SIGGS. What we present here is extracted from a working paper written by Frick and Semmel (10).

In addition to the utilization of the information theoretic

properties of SIGGS, the authors show how graph theoretic properties in SIGGS can be applied in CARTLO. They selected the property complete connectionness, CC, and illustrated how it can encompass Skinner's theory of behavioral modification.

In SIGGS complete connectionness is given as:

$$\frac{\text{number of two-way direct channels}}{\text{max-number of two-way direct channels}}$$

The maximum number of two-way channels can be determined by

$$\frac{n(n-1)}{2}$$

where n is the number of components in the system. CC can vary from 0 to 1. Such variation is independent of the size of the system (the number of components). Thus, a system, such as Skinner's, with only two components can be investigated.

On the basis of Skinner's teacher-learner system, his postulations that reinforcement following specifications tends to increase the probability of such actions whereas deprivation of reinforcement tends to decrease them, and a classification of teacher action relative to reinforcement, hypotheses, as the following, can be stated.

$$H_1: p(T_A/L_1) \uparrow \rightarrow p(L_1) \uparrow$$

$$H_2: p(T_D/L_1) \uparrow \rightarrow p(L_1) \downarrow$$

$$H_3: p(T_N/L_1) \uparrow \rightarrow p(L_1) \uparrow$$

$$H_4: p(T_I/L_1) \uparrow \rightarrow p(L_1) \downarrow$$

where: T_A is teacher approval action to a learner
 T_D is teacher disapproval action to a learner
 T_N is neutral teacher action to a learner
 T_I is teacher non-reaction to a learner, and
 L_1 is a specific learner action.

Full statements of the hypotheses follow.

Hypothesis One: If the probability of teacher approval immediately following a specific learner action increases, then the probability of that learner action increases.

Hypothesis Two: If the probability of teacher disapproval immediately following a specific learner action increases, then the probability of that learner action decreases.

Hypothesis Three: If the probability of teacher neutrality immediately following a specific learner action increases, then the probability of that learner action increases.

Hypothesis Four: If the probability of teacher non-reaction immediately following a specific learner action increases, then the probability of that learner action decreases.

Not only can SIGGS incorporate Skinnerian conceptions of behavior modification, but it permits the conception of education on a more general level. This is illustrated through a hypothesis from SIGGS

$TP \uparrow \rightarrow CO \downarrow \wedge SA \uparrow$

interpreted as

If the uncertainty of teacher actions increases, then within the system compatability decreases and strain increases.

This hypothesis can be tested through information measures (H), shared information measures (T), and multivariate information measures (B). Multivariate measures extend analysis to three or more classifications.

That a holistic approach to research of educational practice is possible through SIGGS is well stated in the concluding statement of Frick and Semmel's occasional paper.

The application of the SIGGS Model on the teaching-learning process would optimally require a complex, computerized data collection system for encoding, storing, and retrieving sequential teacher-learner interaction data, teacher characteristics, learner achievement data, curriculum information, setting characteristics, etc. The system would continually update itself as new data are entered. Measures of information (H) and measures of commonality between probability distributions (T) as well as standard multivariate statistics could be used to test hypotheses generated from the retrodution process. Essentially, the outcome of this configuration would be that, given an adequate data bank, future states of components of systems could be predicted (in a Bayesian sense) from present states.

One major difference between the SIGGS Model and the presage-process-product model is that the negarystem is concomitantly interrelated whenever a system is selected as a focus. Thus, if teacher behavior were of interest in an hypothesis, learner, curriculum, and setting variables would be simultaneously considered as they affect teacher behavior as well as how teacher behavior affects them. In the traditional presage-process-product model, teacher behavior and presage variables have been generally viewed as to their effects on pupil behavior without taking into consideration the simultaneous effect of pupil behavior on teacher or curriculum and/or setting variables. Nor have the simultaneous effects of curriculum variables on teacher and pupil behavior been considered. (11)

IV
SIGGS and Philosophical Educational Research

Since SIGGS gives focus to mutuality of exchange between the teacher and the learner and allows consideration of constructive educational systems (12), SIGGS provides a conceptual framework to develop knowledge about educational systems which enhance the quality of life.

In an educational system which is constructing a teacher must be a learner as well as a teacher. To be both a learner and a teacher, a teacher must do more than relate to students, for students cannot further the learning of their teachers. If students could, they would not require teaching. The relation between a teacher and student is tutorial. Such a relation is onesided. Teachers can help students transcend themselves, become constructing as well as maintaining, but through that relation they cannot themselves transcend.

Teachers, to transcend, must engage in inquiry. To be constructive forces in tutorial relations, teachers continuously must be becoming the best of culture not merely a part that is satisfying. Given the constructive requirement, educational research should be directed toward retroductive rather than inductive processes. What should be sought in educational research are the conditions and structures of teacher-student transactions that are retroductive and proactive.

Philosophical analysis should be directed toward defining, explicating and justifying concepts and principles required for characterizing and designing educational transactions. Philosophical synthesis should be directed toward describing the standards and decisions necessary for realizing the best of culture in educational transactions.

NOTES

1. See E. Steiner's writings on educology: the earliest paper is "Logic of Education and Educatology [Educology]: Dimensions of Philosophy of Education," Proceedings of the Philosophy of Education Society, 1964, and the latest, "Educology: Its Origin and Future," American Educational Research Association, 1977.
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8. Green and Pettigrew, op. cit.
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10. T. Frick and M. I. Semmel, "CARTLO: The Integration of CATTS and SIGGS," Occasional paper, CITH, Indiana University, Bloomington, Indiana, February, 1976.
11. Ibid., pp. 65-66.
12. G. S. Maccia and Elizabeth Steiner, "SIGGS Theory As a Systems Theory for Education Which Enhances the Quality of Life," Proceedings of the 1975 Annual North American Meeting, Society for General Systems Research.